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ORBITAL TRANSFER VEHICLE (OTV) ENGINE STUDY, PHASE A - EXTENSION

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INTRODUCTION AND SUMMARY

The initial Phase A Orbital Transfer Vehicle (OTV) Engine Study Program was structured to identify candidate OTV engine cycle concepts and design configurations, to evaluate and assess the characteristics and capabilities of the candidates, and to determine an interim engine power cycle and engine configuration which can best meet the goals and requirments of the OTV program. In that initial portion of the study program parametric OTV engine data (performance, weight, cost) were generated and made available to OTV system contractors.

The OTV engine will be used to power the Orbital Transfer Vehicle that is carried into low earth orbit by the Space Shuttle. The OTV engine has the major objectives of high payload capability, high reliability, low operating cost, reusability, and operational flexibility. The OTV engine study is based upon 1980 technology. Preliminary cost data were also generated during initial Phase A studies.

Recognizing the reliability potential of the expander engine cycle and taking full advantage of continuing evaluation studies, through Phase B definition, by both vehicle and engine contractors, Rocketdyne recommended that both the staged combustion and expander engine cycles be continued through the OTV Vehicle Definition phase.

The current Phase A-Extension of the OTV engine study program will provide additional expander and staged combustion cycle data that will lead to design definition of the OTV engine. The proposed program effort will optimize the expander cycle engine concept (consistent with identified OTV engine requirements), investigate the feasibility of kitting the

staged combustion cycle engine to provide extended low thrust operation, and conduct in-depth analysis of development risk, crew safety, and reliability for both cycles. Additional tasks will address costing of a 10K thrust expander cycle engine and support of OTV systems study contractors.

The contracted extension effort includes five additional technical tasks and one reporting task. The scheduling for these tasks is shown in Fig. 1. The program began with an orientation briefing at NASA-MSFC to discuss details of the work to be accomplished. At this briefing, Rocketdyne presented the approach of the program study plan, identified all tasks, their objectives, expected results, man-hour allotments, and program milestones.

As indicated in Fig. 1, effort continued on Tasks 9, 10, and 11. Task 9 was completed during the report period; the final report for this task is presently in preparation and will be released shortly. Approximately 90 percent of the total planned man-hours have been expended in above efforts. This work is discussed in the main body of this report.

ROCKETDYNE OTV PHASE A ENGINE STUDY EXTENSION

(NAS 8–32996)

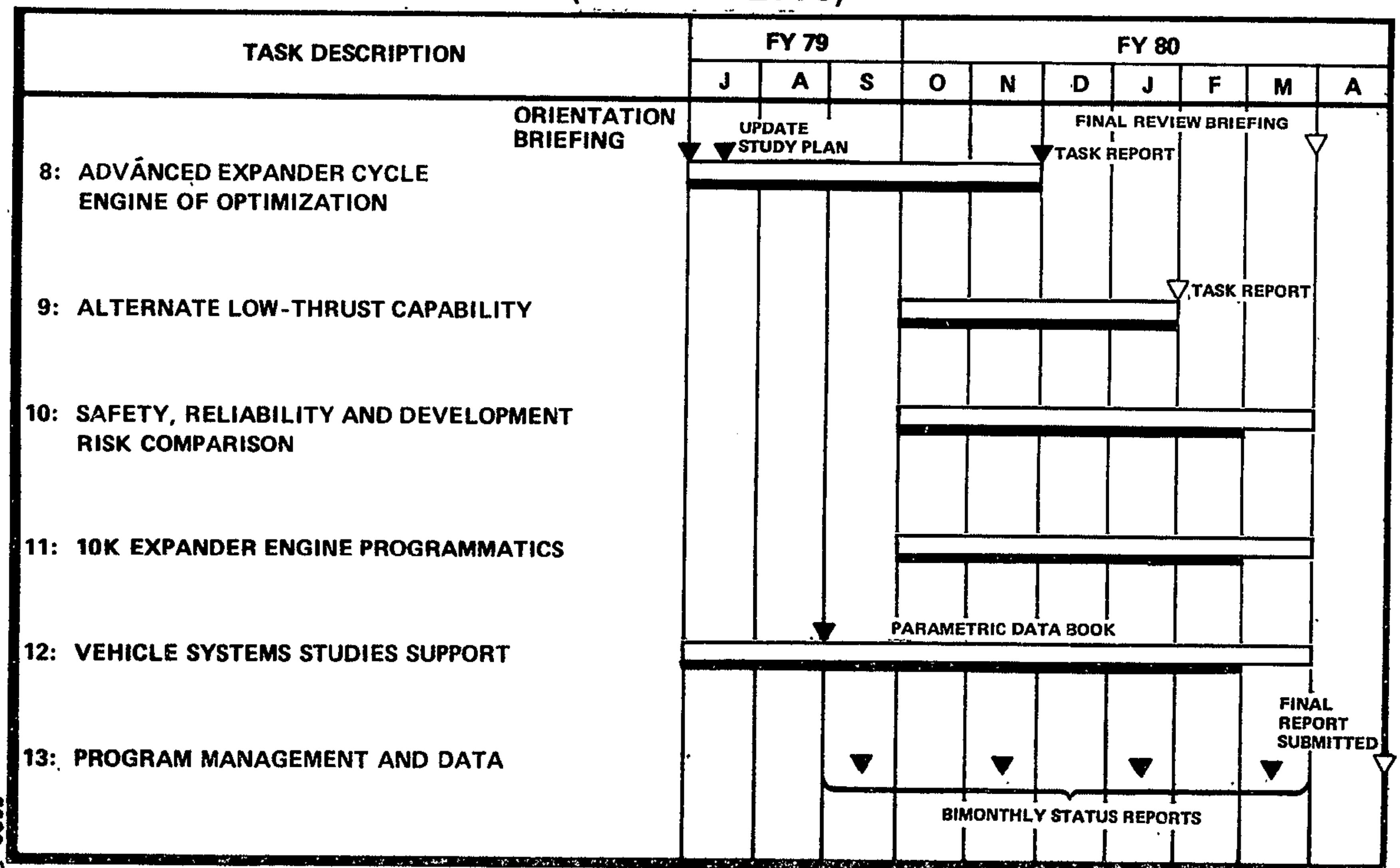

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Figure 1. OTV Phase A – Extension Schedule

DISCUSSION

TASK 9. ALTERNATE LOW THRUST CAPABILITY

The results of the study of extended low thrust operation of the OTV staged combustion engine indicate that long life, high performance operation of the engine in the low thrust mode (1-2K level) can be achieved with minimum modification (kitting) of the engine.

Modifications to the OTV 20K staged combustion engine which were considered were:

(1) Removal of the preburner injector, since in pump-fed idle the engine is run in an expander mode and does not require a preburner. Removal of the preburner injector increases the available turbine inlet pressure to the drive turbines. The preburner LOX line and valve can be removed in order to simplify the system.

(2) Modification of the main injector to increase the oxidizer side pressure drop so that potential feed system coupled instability is avoided. Two approaches are possible; one is to use a LOX post insert which incorporates an orifice to increase oxidizer side pressure drop, a second approach is to braze on new LOX posts which incorporate a smaller flow area.

(3) The use of fuel pump recirculation in order to avoid the positive slope region of the pump H-Q curve. This modification would add a line and valve from the pump discharge to the pump inlet in order to recirculate hydrogen and keep the pump at a higher

flowrate. Computer model studies have indicated that this is an effective method to avoid pump instability problems when operating at low flow conditions. The computer modeling has included the effect of propellant heating which occurs when pump recirculation is used.

(4) Modifications to the hydrogen pump could be considered in order to have a pump H-Q curve without a positive slope region at low flow conditions. A modified fuel pump can be derived by a variety of changes, such as: (1) increased sweepback of the impeller blades to make the H-Q curve have more negative slope, (2) decrease the impeller O.D. to allow the pump speed to increase and operate at a more favorable Q/N, (3) decrease the tip width (B2) of the impeller in order to modify the H-Q characteristic, and (4) redesign the first stage crossover diffuser to avoid stall at low flowrates.

Each of these modifications were considered and evaluated by means of the OTV staged combustion transient computer model.

The modifications which are recommended for kitting of the OTV staged combustion engine are: (1) removal of the preburner injector, (2) modification of the main injector to improve feed system stability, and (3) the use of fuel pump recirculation to avoid fuel pump operation in the positive slope region of the H-Q map. Modification of the fuel pump such as changes to the impellers would require more extensive fuel pump modification and development and could be considered as alternatives to the use of fuel pump recirculation.

TASK 10. SAFETY, RELIABILITY AND DEVELOPMENT RISK COMPARISON

The objective of this task is to perform comparative analyses in the following areas: (1) crew safety, (2) mission success, and (3) development risk with respect to DDT&E program schedule advances or slippages.

During the report period the areas of OTV engine manrating, safety and reliability were investigated in-depth and the results presented at MSFC on January 24, 1980. The presentation covered the following aspects of the task subject:

(1) A review of past and current manned space vehicle propulsion safety and reliability criteria.

(2) A review of the OTV propulsion system safety and reliability issues.

(3) Rocketdyne's suggested approach for OTV engine manrating, safety and reliability.

The significant results and findings in these three areas are discussed in the following.

Past and Current Manned Vehicle Programs

The review showed that various reliability approaches had been used in the past for manned vehicle engines including the present Space Shuttle Program. The approaches are summarized in Tables 1 and 2.

TABLE 1. ENGINE RELIABILITY CRITERIA FOR PAST AND CURRENT MANNED SPACE VEHICLES

	VEHICLE	ENGINE RELIABILITY GOAL	VERIFICATION
EXPENDABLE ENGINES	• MERCURY ATLAS • GEMINI TITAN I	.85	TEST DEMONSTRATION: 100 TESTS; 90% CONF
	• SATURN BOOSTERS H-1 F-1 J-2	.99	TEST DEMONSTRATION: 69 TESTS, 50% CONF
	• APOLLO SPS LEM DESCENT LEM ASCENT	.9999 .9991 .999982	DESIGN VERIFICATION TESTS QUAL TESTS CERTIFICATION
REUSABLE	• SPACE SHUTTLE SSME OMS RCS	NO NUMERICAL GOAL	DESIGN VERIFICATION SPEC'S LIFE REQUIREMENTS CERTIFICATION

TABLE 2. SUMMARY OF PAST AND CURRENT ENGINES FOR MANRATED PROGRAMS

• PAST ENGINES - MERCURY, GEMINI, SATURN, APOLLO • EMPHASIS ON HIGH RELIABILITY; ENGINE SAFETY NOT EXPLICITLY ADDRESSED • SOME PROGRAM NUMERICAL GOALS FOR RELIABILITY WERE DEMONSTRATED • FEW REDUNDANT ENGINE COMPONENTS • LIMITED ENGINE OUT CAPABILITY
• CURRENT ENGINES - SPACE SHUTTLE • EMPHASIS ON SAFETY AS A TOTAL PROGRAM COMMITMENT • QUALITATIVE TREATMENT OF RELIABILITY • ENGINE OUT CAPABILITY FOR SAFE RETURN CONSIDERED IMPORTANT • REDUNDANCY OF SELECTED ENGINE COMPONENTS

It is apparent from these tables that the Shuttle Orbiter engines use a different approach to safety and rèliability compared to previous space flight programs.

Prior to the Space Shuttle, emphasis was mainly on high reliability for safety. Numerical reliability goals were imposed on the engines by specifications and were either to be demonstrated (H-1, F-1, J-2) or were given as an allocation goal without demonstration (SPS, LEM engines).

Early manned space flights used boosters designed for ballistic missiles, and reliability requirements were based on military objectives. Later Saturn and Apollo engines had specific numerical reliability such as design analysis, redundancy requirements, design verification specifications and qualification testing and formal certification programs were instituted. Engine safety was not addressed explicitly as a design criterion. Engine out capability early in the mission was limited to the Saturn I B first stage powered by eight H-1's. The first and second Saturn V stages had engine out capability only in the late boost phases of each stage.

The engines for the Space Shuttle Orbiter do not require quantitative reliability demonstration. Emphasis is on safety as a total program commitment and as an explicit design objective reflected in specifications and program plans. Reliance is placed on engine out capability during mission abort for crew safety, and greater engine component redundancy than in the past.

OTV Propulsion Safety and Reliability Issues

The following points are considered major issues for OTV propulsion man-rating, safety and reliability:

(1) Do current NASA specifications for the STS and for previous manned space programs adequately cover safety criteria for OTV propulsion, specifically during space flight? A review of the appropriate NASA documents revealed that they contain many basic STS requirements but no specifications were found specifically applicable to OTV engines during space flight.

(2) Which OTV propulsion system configurations are best for mission success and for crew safety from the standpoint of highest success probability?

(3) How is engine reliability affected by:
   a. The number of engine tests,
   b. Engine component redundancy, and
   c. Demonstration requirements of reliability goals?

(4) What is a viable OTV engine design approach for safety and reliability?

The study assumed as a groundrule OTV crew safety independently from the existence of life boat or rescue vehicles. The answers to points 2, 3 and 4 are summarized under the next heading.

Suggested Approach for OTV Engines

The suggested safety and reliability approach for OTV engines is as follows:

(1) Use Current STS Propulsion System Approach for Safety and Reliability

This approach emphasizes design-to safety and reliability, featuring

thorough safety and reliability analyses of the design and extensive design verification by test or analysis. Demonstration of numerical reliability goals (as done for H-1, F-1, J-2) is not considered cost effective.

(2) Best Propulsion System Concept with Regard to Mission Success and Crew Safety

Mission Success: Two main engines, with either engine capable of mission completion after the first burn occurred with both engines.

Crew Safety: Two engines with backup propulsion. Either main engine or the backup propulsion are capable of safely returning the OTV and its crew from any point in the mission.

The capability of a backup propulsion for crew safety needs to be investigated and firmly established.

(3) Engine Design Features for Safety and Reliability

The OTV engines should have specific features to enhance safety and reliability. Major features are as follows:

Selected Component Redundancy: Safety critical components should be made redundant. This includes the controller, igniters and critical flight instrumentation.

Fail Safe Components: Fail safe features, such as valve closure upon loss of signal should be incorporated wherever they improve safety and do not degrade mission success.

<u>Protection Against Common Mode Failures</u>: Design protection against common mode and non-independent failures should be provided to the greatest possible extent. This includes separation, proper placement, and hardening of vital components.

<u>Engine Checkout and Health Monitoring System</u>: The engine design should include a checkout and health monitoring system which automatically checks for failures, alerts the crew if redlines are exceeded, and shuts down the engine prior to the occurrence of hazardous failures.

EFFORT DURING NEXT REPORT PERIOD

During the next period the Task 11 10K expander engine programmatics task will be completed and the final report will be submitted. The final review is tentatively scheduled to be held at MSFC on 16 April 1980.